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There exists a continuing need for empirical data in order to validate predictive codes for projectile/gun dynamics. The parameters that affect projectile accuracy are not well defined, and the instrumentation and analysis techniques are continuously being improved to allow the measurement and engineering analysis required to document projectile accuracy effects. This report documents a firing test which had the objectives of establishing measurement and analysis techniques, establishing the relevance of the parameters being measured, and determining the feasibility of making additional measurements in the investigation of gun system dynamics.

The measurement techniques discussed include the use of microwave doppler radar and the Muzzleschmidt technology. Doppler radar analysis makes use of high resolution Fast Fourier Transforms to give an insight to projectile performance both in-bore and during free flight. Although the detailed results of the Muzzleschmidt measurements are discussed in other

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reports, the approach, its relationship to the other instrumentation, and references are included.

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MEMORANDUM REPORT BRL-MR-3581

MICROWAVE RADAR TECHNIQUES APPLIED TO GUN ACCURACY MEASUREMENTS

B. T. HAUG

APRIL 7, 1987

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I. INTRODUCTION

As a part of the Ballistic Research Laboratory's (BRL's) Ballistic Technology Program, there is a continuing effort to study accuracy and the parameters that affect it. A significant long term objective of this program is to develop a comprehensive validated gun dynamics methodology for predicting in-bore and launch force histories to aid in the structural analysis of projectiles and the predicting of final launch parameters insofar as they affect accuracy. The goals of the initial testing documented in this report were to establish measurement techniques, to initiate a determination as to which measurements should be continued in future tests, to evaluate the relevance of the parameters measured, and determine the feasibility of making additional measurements.

Although this report will discuss aspects of all the instrumentation and data acquisition involved in the initial testing, the discussion of the analysis of the data will concentrate on the microwave radar measurements, specifically the attempts to measure in-bore behavior and spin. Muzzleschmidt data[1] and the correlation of the muzzle data with that from the microwave is left to other papers. The initial objective in making microwave measurements was to determine the tangential projectile velocity from shot start to just prior to the impact in the sandbutt at the end of the range. Additionally, it was desired to measure the spin history of the projectile and the transverse projectile motion. With a one-dimensional fixed position radar unit only a qualitative analysis of transverse motion can be made; however, it was hoped that any information obtained could be compared to theoretical predictions of projectile motion to include those developed by F. V. Reno[2] and L. H. Thomas[3] and the current work being done by S&D Dynamics under contract to BRL.[4]

II. PRELIMINARY PREPARATION

A 37-mm cannon was chosen as the test system because it was available in the laboratory, it could be fired in our indoor ranges, a supply of proof slugs was in our possession, and the tube was an easy size to work with as far as the Muzzleschmidt and the microwave were concerned. Before installing the tube in the range, it was sent to the Combat Systems Test Activity for stargaging and a copy of the report is included as Appendix A. By stargaging the tube it was possible to establish the condition of the tube. With this information, gun wear and build up could be included in the analysis of the microballistics. An extensive analysis of the pattern of the wear and build up was conducted by Dr. Rurik Loder and Mrs. Emma Wineholt.[5]

Additional preparation of the gun tube was done at BRL. Threads were cut on the muzzle to allow the Muzzleschmidt and the muzzle weight to be attached, as shown in Figure 1. The dual four coil Muzzleschmidt, developed by Jimmy O. Schmidt at BRL, was designed to determine the angle of the projectile relative to the gun tube at shot exit, as well as the rate of change of this angle.[6] This measurement system was to be evaluated as a part of this test. To reduce the number of parameters that had to be considered in the analysis, a muzzle weight was designed to restrain the transverse muzzle motion until after projectile exit. This eliminated the requirement to measure angular muzzle motion. The muzzle assembly incorporated the coils and oscillator box of the Muzzleschmidt and the muzzle weight which combined to add 27.2 kg (60 lbs) to

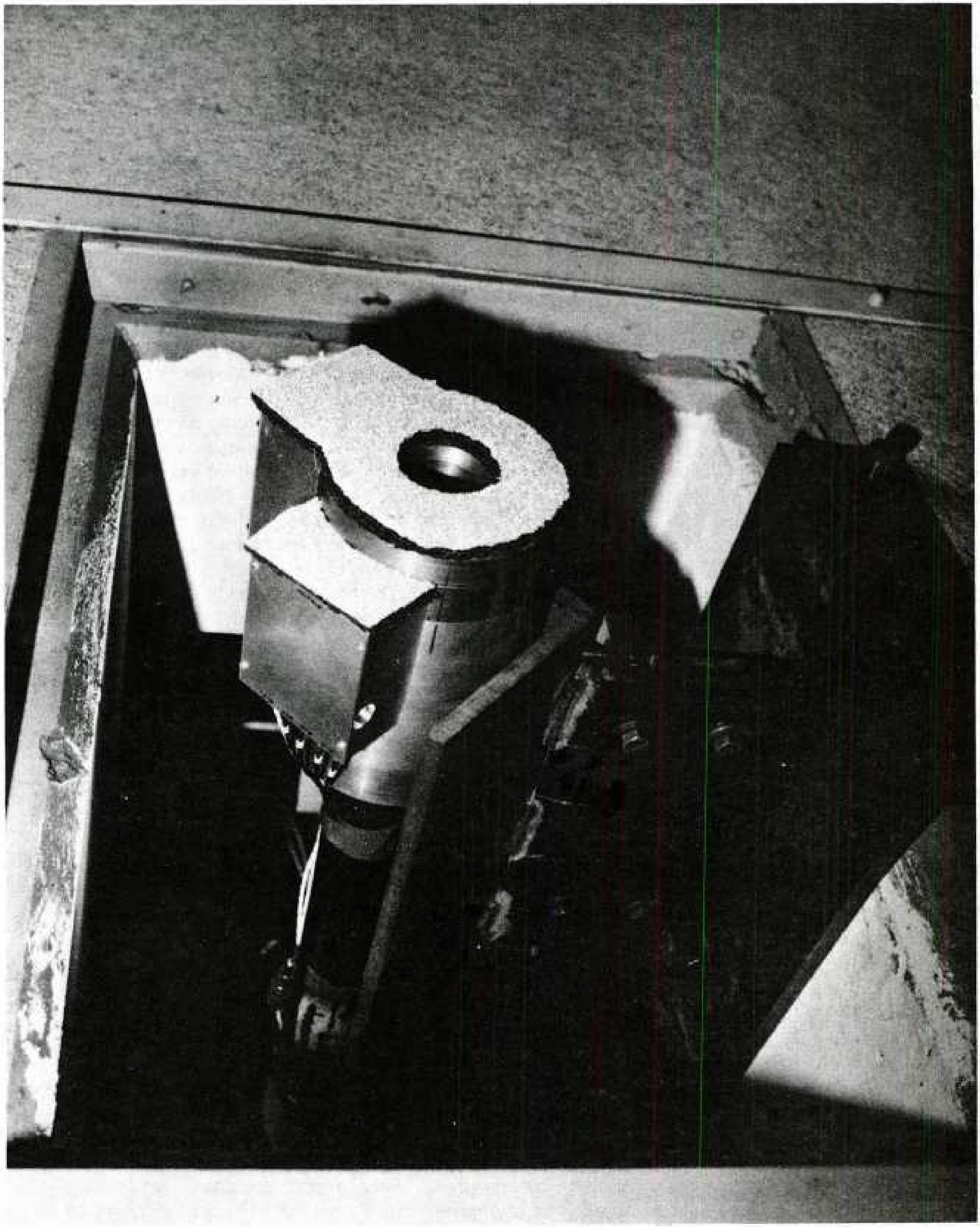


Figure 1. Photograph of the Muzzleschmidt and Muzzle Weight

the mass of the muzzle. A V-block was designed to support this additional weight.

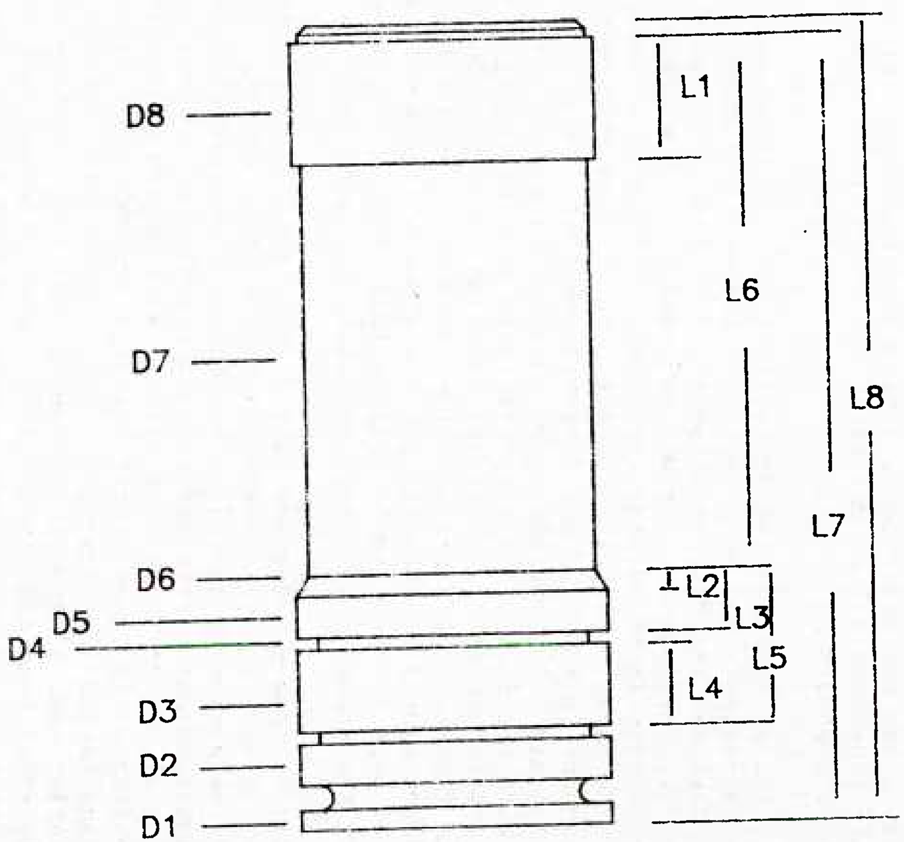
The 37-mm gun tube was mounted on a Frankfort rest which was then bolted to the I-beams in the range with the muzzle just protruding through the blast window. The V-block required to support the muzzle weight was placed in the blast window. An optical tracker was used to confirm the effectiveness of the muzzle weight by measuring vertical muzzle displacement prior to shot exit. The recoil was measured by another optical tracker to check the functioning of the recoil buffer and to obtain a value for the recoil prior to shot exit.

Percussion primers were used, and it was decided to fire the gun with a lanyard rather than to attempt to arrange a solenoid firing mechanism and risk electrical interference on the data lines. In the past current surges in the firing solenoid have been a source of noise in the data.

To check out the Muzzleschmidt, two different size proof slugs were selected for this test, experimental projectiles designated as type 508 and 510. Some projectile modifications were done to improve the instrumentation results. To enhance the profile seen by the muzzle device, the projectiles were modified by machining a step on the leading edge of the bourrelet. In addition three parallel v-shaped grooves were cut in the face of some of the projectiles to emphasize projectile spin in the microwave return. A typical projectile is shown in Figure 2 with the dimensions of concern shown. The projectiles were measured carefully by personnel from Launch and Flight Division, BRL, and the weight, the location of the center of gravity and the linear dimensions were all documented. The dimensioned rounds that were fired are listed in Appendix B.

In an attempt to check the symmetry of the engraving and to determine if asymmetric engraving might be a factor in projectile accuracy, a soft recovery system was designed in order to allow a visual inspection of the rotating band of the recovered projectile. It was conceded that it would be impossible to catch a projectile in the distance available without some damage to the projectile and band, but if the velocity could be reduced to a point where the damage on impact in the sand would be minimal then some analysis of the rotating band might be possible. Two 55 gal. drums were adapted to this purpose. With the ends removed and replaced with cellotex, the drums were half filled with a soft clay material intended to be used to absorb oil spills on concrete floors. The drums were then laid end to end horizontally on stands and positioned so that the gun was aimed at the lower half of the barrels. By only filling the barrels halfway, the clay could expand when impacted by the projectile without splitting the barrels.

A 10GHz microwave radar was placed approximately 18.25m (60ft) downrange along side the soft recovery barrels and aimed back towards the muzzle. The most effective alignment technique was to use a reciprocating saw with a large washer mounted normal to the reciprocating motion of the saw so as to present a large frontal surface approximately the area of the projectile face. The saw was positioned in front of the muzzle with the washer aligned along the shot line and facing the microwave. The reciprocating surface moving with such regularity made alignment and tuning positive. As long as the angle between the radar beam and the gun tube center line was kept small, the microwave signal could be propagated down the tube to the face of the



Dimensions	Type 508	Type 510
L1 (mm)	14.70	12.29
L2	4.40	4.29
L3	7.18	7.16
L4	9.33	9.30
L5	18.66	18.64
L6	66.92	16.43
L7	100.67	50.08
L8	105.81	55.37
D1	36.56	36.55
D2	36.52	36.55
D3	38.25	38.25
D4	36.91	36.88
D5	38.25	38.23
D6	37.18	37.18
D7	36.53	36.53
D8	36.87	36.86
Weight (g)	867.9	456.0

Figure 2. Typical Projectile Dimensions

projectile and back to the antenna. The center of the antenna dish was less than one meter from the line of flight and 18.25m downrange. Every effort was made to minimize the signal return caused by the recoiling parts of the gun by covering the muzzle face with microwave absorbing material which can be seen in Figure 1.

The only additional data taken were chamber pressure and targets. The pressure gage was a mini-hat gage mounted in the chamber. This required the cases to be drilled which is a standard procedure for measuring chamber pressure with an externally mounted gage. An attempt was made to measure downrange targets. The aim point was determined using a modified boresight and the impact point recorded using a witness card. The standard 37-mm boresight could not be used because the tapered collar used to center the sight was too short to reach through the muzzle device and center on the bore. An adapter was manufactured in the BRL shop.

This completes the description of the instrumentation and equipment in the range, and Figure 3 shows the arrangement of each component of the test. Note in particular the location of the microwave unit, as this is not the conventional location used in most ballistic tests. Figure 4 is a photograph of the gun, showing the pressure gage and one of the Optrons. Notice the Muzzleschmidt attached to the muzzle.

III. DATA ACQUISITION

The data were acquired on analog tape with some channels backed up on the digital data acquisition system. This was not the usual procedure for the recording room where the digital recording was the primary system; however, the microwave data were better handled by tape so that the data could be post processed using the HP1000 A/D facility. The microwave signal was recorded on three separate channels. The signal was low pass filtered, dc-10 KHz, allowing the shot start motion to be recorded on a wide band FM channel. With the low pass filter, the doppler signal from the projectile was attenuated as the projectile velocity increased leaving only the contribution from the recoiling gun parts. This low pass filter was used to obtain the early motion of the projectile and to get information about gun recoil. Since the frequency of the doppler signal is proportional to the velocity of the projectile, recording a second channel using a bandpass filter of 1 kHz - 80 kHz insures a continuous measurement of the projectile travel by overlapping the frequency content of two channels. This second channel recorded the projectile travel from shortly after shot start until the projectile left the view of the microwave unit, and successfully eliminated the signal contribution from the recoiling gun. This allowed the return from the projectile to be futher amplified without the clipping that would have occurred if the large amplitude doppler signal due to recoil were still present. As a back up, and from experience, it was decided to also record the microwave return on a direct record channel using the same bandpass filter settings. It should be noted that the bandpass filter, in particular the highpass portion, was applied before any amplification to prevent clipping due to the return from the recoiling gun. In our A/D facility, data that have been recorded on a direct record tape channel may be time scaled to a greater extent, and the additional samples created are valuable in the high resolution spectrum analysis. Thus, the recording procedure was selected with consideration given to the requirements of the analysis, in particular, the

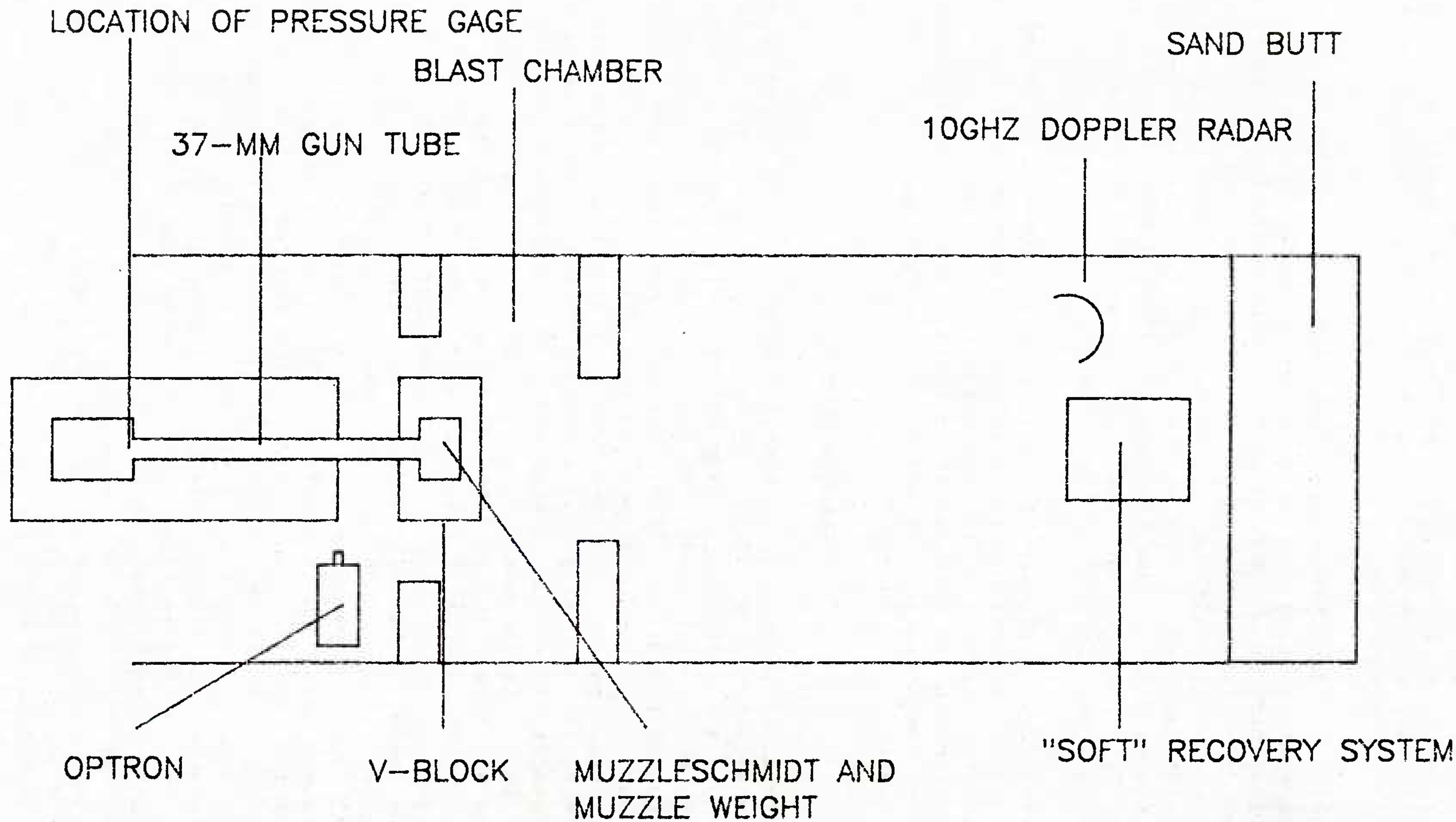


Figure 3. Diagram of the Range Set-Up

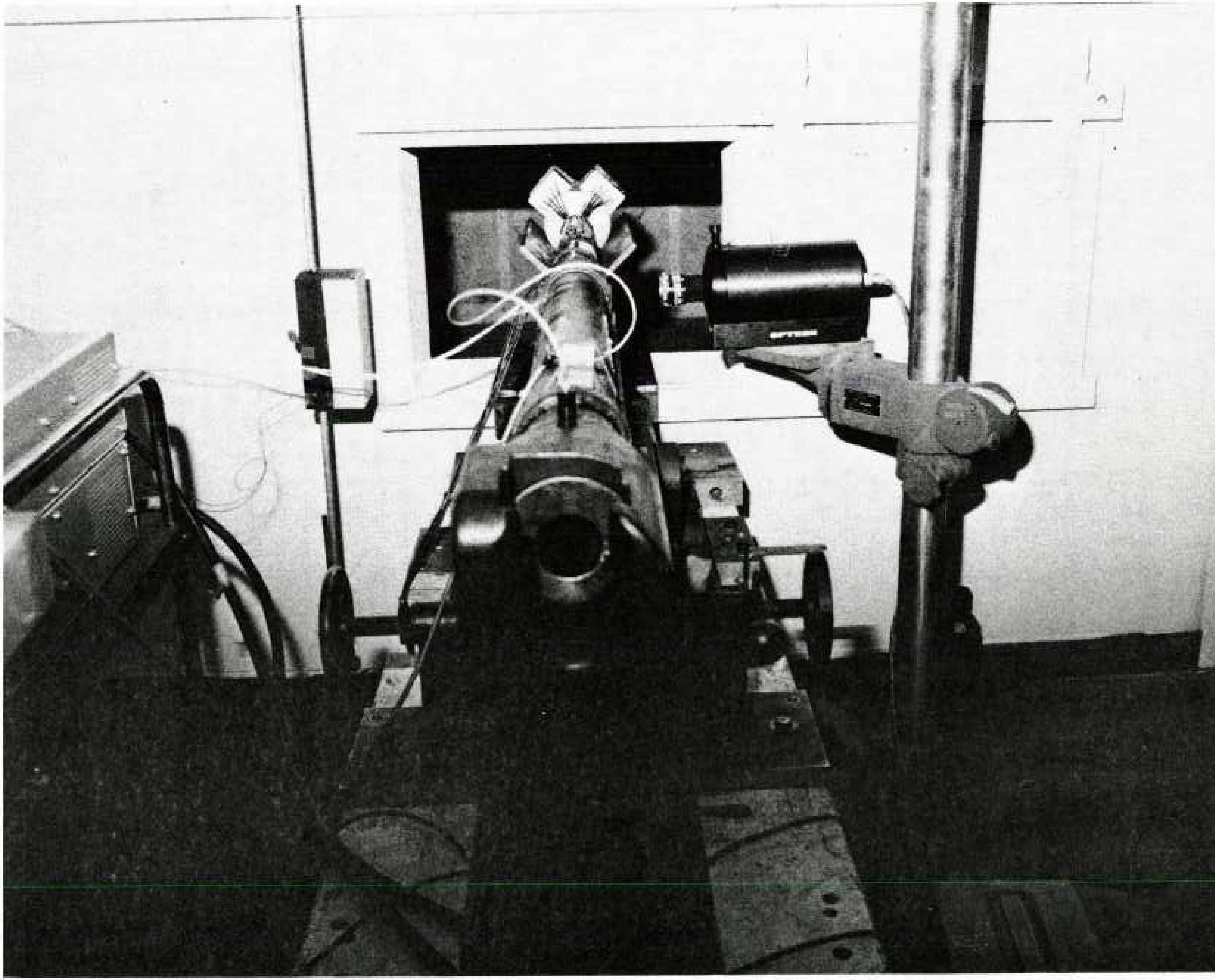


Figure 4. Photograph of the 37-mm Cannon

spectrum analysis of the microwave return. Other data recorded on analog tape included chamber pressure, a firing fiducial, and a muzzle exit fiducial generated by the Muzzleschmidt.

The dual four coil Muzzleschmidt is made up of two sensors separated by 2.54 cm. Each sensor consists of four coils and the output of each coil is proportional to the distance between the coil and the metal parts of the projectile. The outputs of the coils are combined to form up-down, (U-D), up+down, (U+D), left-right, (L-R), left+right,(L+R), for both sensors. For this test the eight outputs from the muzzle device were captured on transient waveform recorders, Biomation model 805's. The transient recorders used did not have an output bus directly compatible with the HP 9845 which was the computer available to read them. Earl Ball, an electronics technician at BRL, designed and assembled the required interface between the eight units and the HP 9845. As is the case whenever one has only the correct number of units and no spares, one of the Biomations failed and for most of the test only seven channels were recorded. In the analysis, the differences, L-R and U-D, for each sensor were critical but it was not necessary to record all the sums, so the results were not compromised by the failure of the equipment.

IV. CONDUCT OF THE TEST

The initial firings were used to test the new Muzzleschmidt instrumentation and to experiment with different methods of implementing and recording the microwave. Considerable effort and time was expended to ensure that the muzzle device was operating as designed and that the mounting procedure did not allow vibrations to alter the signal. The method of mounting the muzzle device had to be changed and then checked out again. During this process the techniques for handling the microwave measurements were firmed up.

Initially the tube was purged with nitrogen prior to each shot because it was felt that this inert gas would improve the transmission of the microwave signal during the in-bore cycle. At one point the supply of nitrogen was depleted but the firing was continued with no apparent change in the resulting microwave return; therefore, the procedure was changed to simply cleaning the tube prior to each shot. Several attempts were made to reflect the microwave beam down the tube from an aluminum plate and also a screen, but these attempts did not meet with the success experienced with aiming the microwave directly at the muzzle from downrange as was described earlier in the discussion of range preparation. Attaching the microwave absorber to the muzzle face reduced the signal strength of the reflection from the muzzle prior to shot exit, but after shot exit the absorber was ripped off with the blast and recoil was clearly visible. The only successful way to eliminate this signal was to filter it out. This experience was what led to the recording technique using multiple channels to record overlapping frequency bandwidths, which then represent the complete projectile velocity record.

Once the Muzzleschmidt was working properly and had been calibrated it was decided to fire a series of at least ten type 508 proof slugs at a reduced charge. Details of the projectile shape and dimensions are presented in Appendix B. Using this projectile made the measurements with the muzzle device easier to analyze due to the long section with constant diameter between the bourrelet and the rotating band. The procedure for firing the series was as follows:

1. Clean tube after each shot in an attempt to get better microwave records;

2. Place a new target downrange and mark the aim point as seen from muzzle sight;

3. Cover the muzzle face with microwave absorber to reduce the magnitude of the return due to recoil;

4. Record temperature and dew point for the gun room, blast chamber and range;

5. Record the actual microwave frequency;

6. For projectiles with grooves, note the orientation of the grooves as loaded in the gun.

By this time the idea of the soft recovery system had been abandoned because the projectiles were still being subjected to sufficient abrasion to alter the appearance of the rotating band. The initial projectiles that were recovered did show evidence of contact between the bourrelet and the gun tube. The recovery system slowed down the projectiles enough that the damage from the impact in the sand was reduced, and some analysis of the in-bore performance of the projectile could have been done. Future testing might have requirements that would benefit from this system, but at this point it was felt that there was no need to slow down the testing by using this device.

After a few rounds to check out the instrumentation, twelve of the machined 508 rounds were fired over a period of several days. The firing pace was determined by our ability to look at the data, make appropriate changes in the recording room and align the microwave unit which was reluctant to work consistently. For the sake of any future analysis that might be done on this base line of firings, Appendix C lists the details of each round and a summary of the success or failure of the different measurements for each round.

Spectrum analysis of the microwave data from some of the preliminary rounds and this series of twelve showed details of shot start and possible balloting motion. The initial shots were all 510 projectiles, the lighter steel projectile. These rounds had shown evidence of balloting at muzzle velocities approaching 1000 m/s. At least one of the heavier and longer 508 projectiles showed some stop and go motion very early in the launch cycle. An attempt was made to try to launch the heavier projectiles at 1000 m/s to allow direct comparison of the doppler signal using Fast Fourier Transforms (FFT's) and waterfall plots. The charge weight was increased until the chamber pressure approached the design limits of the breech, and the projectile velocities obtained were 775 m/s. This was the highest velocity we could obtain using the propellant available for this test. Since this was short of our goal, additional light 508 projectiles were fired at reduced charge weight to attempt to match velocities. Velocities for the 508 projectiles dropped to around 800 m/s, which allowed good comparisons to be made. The details of the analysis are covered in a report by Dr. J. N. Walbert.[7]

V. RESULTS

To demonstrate that the grooves on the face of the projectile would allow the measurement of spin, a projectile that had the V-grooves cut in it was chucked in a drill using a rod threaded to the projectile base. The microwave radar was aimed at the spinning projectile and various spin rates were tried. The resulting signal showed spin very clearly when analyzed on the spectrum analyzer, although it was not readily visible to the eye in the raw data. Several tests were recorded on analog tape and reduced using the Fast Fourier Transform programs. A plot of the results for a projectile with three V-shaped grooves typical of those fired is shown in Figure 5. The primary frequency at 28 Hz represents a measured spin of 1680 rpm. Because of the symmetry of the grooves there is a peak at twice the frequency of the spin. Several suggestions to improve the spin measurements were made, including the attachment of a thin semicircular plate to the front of the projectile, or simply machining a flat-bottomed groove rather than the v-shape that was chosen for the firing tests. To help in the understanding of the results a projectile was machined with three flat grooves radiating at approximately 120° from the center and was tested on the drill. The resulting FFT is shown in Figure 6, and the primary frequency is 24 Hz at 1440 rpm and harmonics are more pronounced due to the groove arrangement. The question of what contribution the grooves make to the measurement of spin is addressed by Figure 7. This plot was the result of spinning a projectile with no grooves, so why was the spin frequency so visible? Apparently the wobble of the projectile in the drill sufficiently changed the radar cross section to allow the doppler to measure spin and since each of the projectiles tested mounted in the drill chuck at slightly different angles, the projectile wobble contributed differently to the amount of spin information in each test. The primary frequency component in the drill tests was due to the misalignment of the projectile in the drill. The groove arrangement determined which harmonic of the spin was emphasized in the radar return.

Figure 8 was derived from actual data from the firing test. A section of the microwave data taken after muzzle exit was analyzed using periodic continuation to generate a high resolution FFT and the results show the velocity and the spin. The velocity can be computed to be 619 m/s. Using this as an estimate of muzzle velocity and a twist rate of 1:25 calibers, the expected spin rate would be 670 rps. Because of the symmetrical geometry of the nose of the projectile, the expected frequency due to spin would be twice the spin rate, 1340 Hz. The side lobes on the spectrum are 1287 Hz away from the center frequency, and which represents 96% of the calculated full spin. The techniques required to extract in-bore spin from the doppler signal are still to be developed, and analysis will be complicated by the existance of balloting motion. Balloting creates multiple path reflections and can vary the energy content of different transmission modes in the gun tube causing shifts in the frequency of the return from the projectile.

Overlapping FFT's of the microwave data were plotted in a waterfall format to reveal a velocity time history. The horizontal axis is the frequency of the doppler signal which is proportional to the velocity of the projectile and time progresses up the vertical axis. Figure 9 is a waterfall plot that includes a portion of the in-bore cycle, muzzle exit, and a short section of free flight. Muzzle exit occurs at the apparent jump in the frequency. This jump is do to the change from waveguide mode to free space

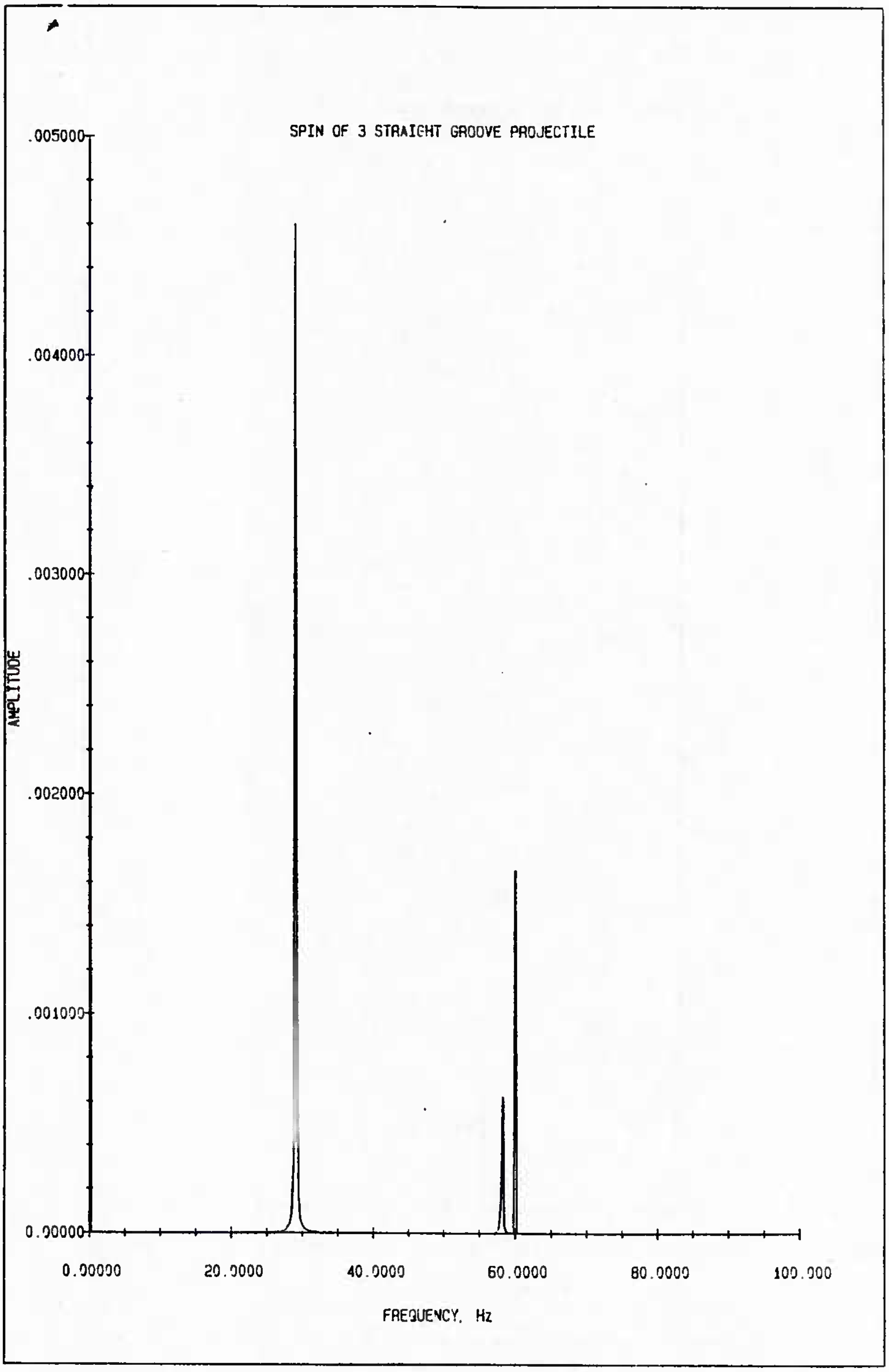


Figure 5. Spin Test for Projectile with V-Grooves

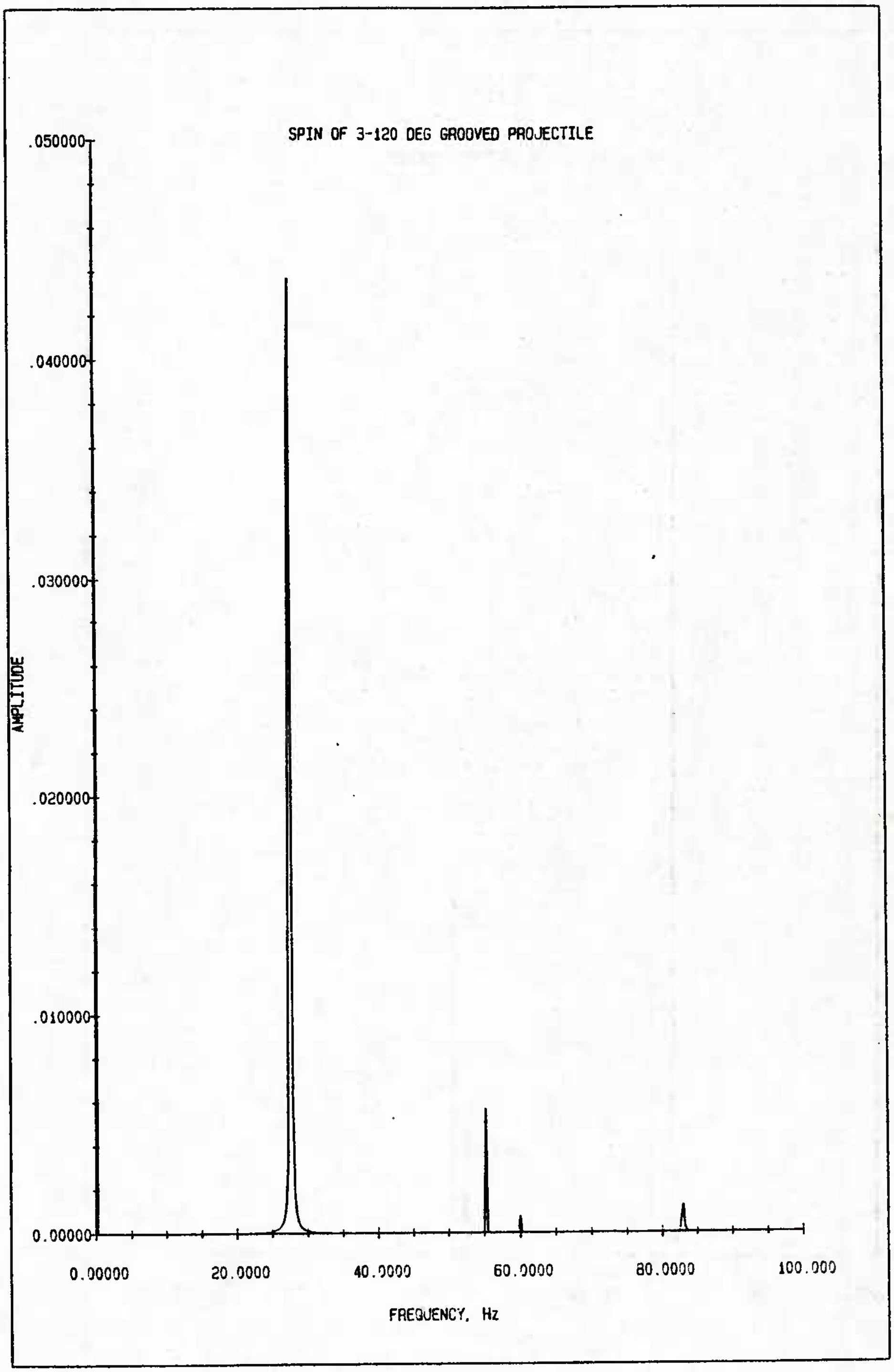


Figure 6. Spin Test for Projectile with Three Flat Grooves

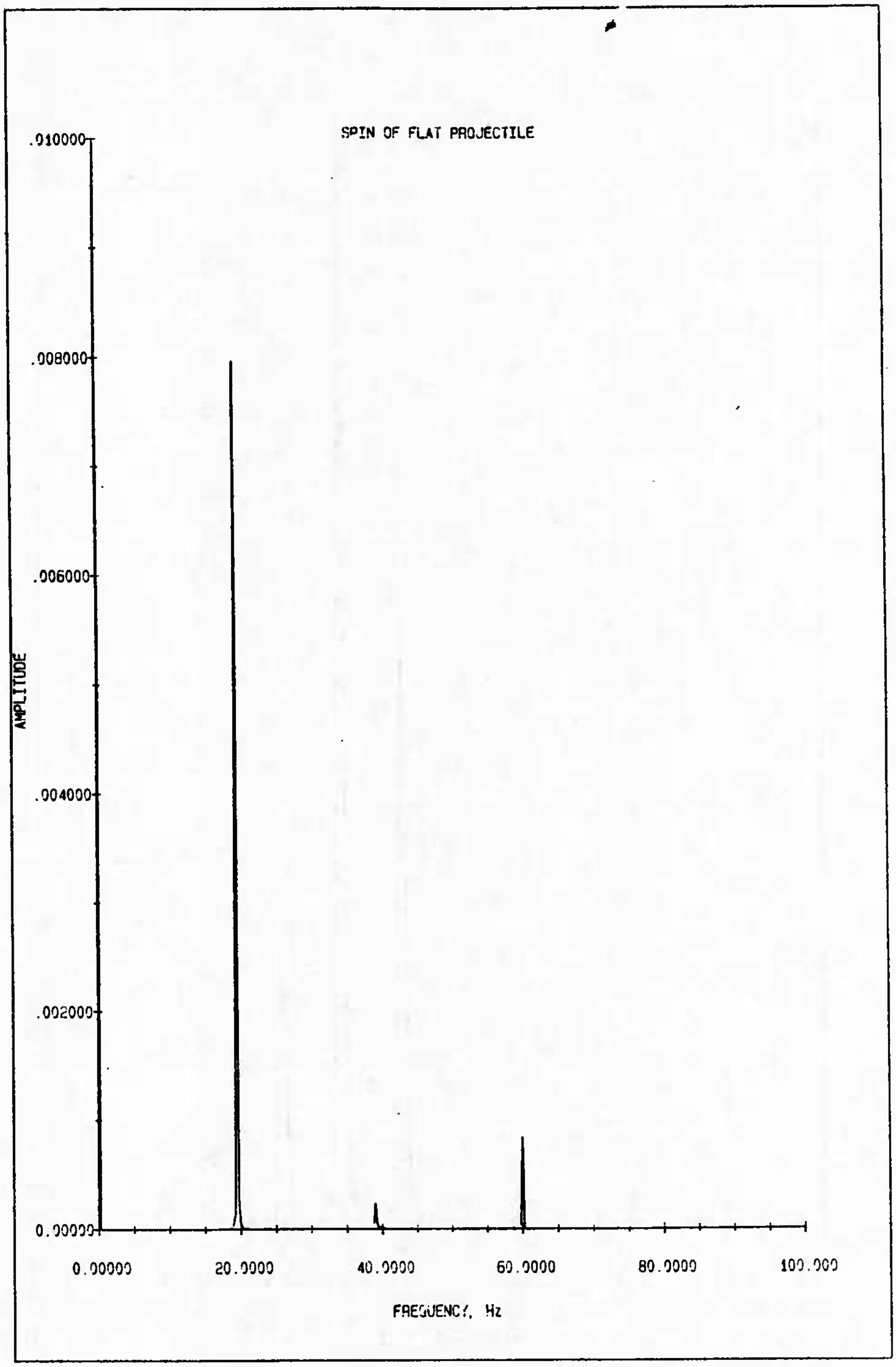


Figure 7. Spin Test for Projectile without Grooves

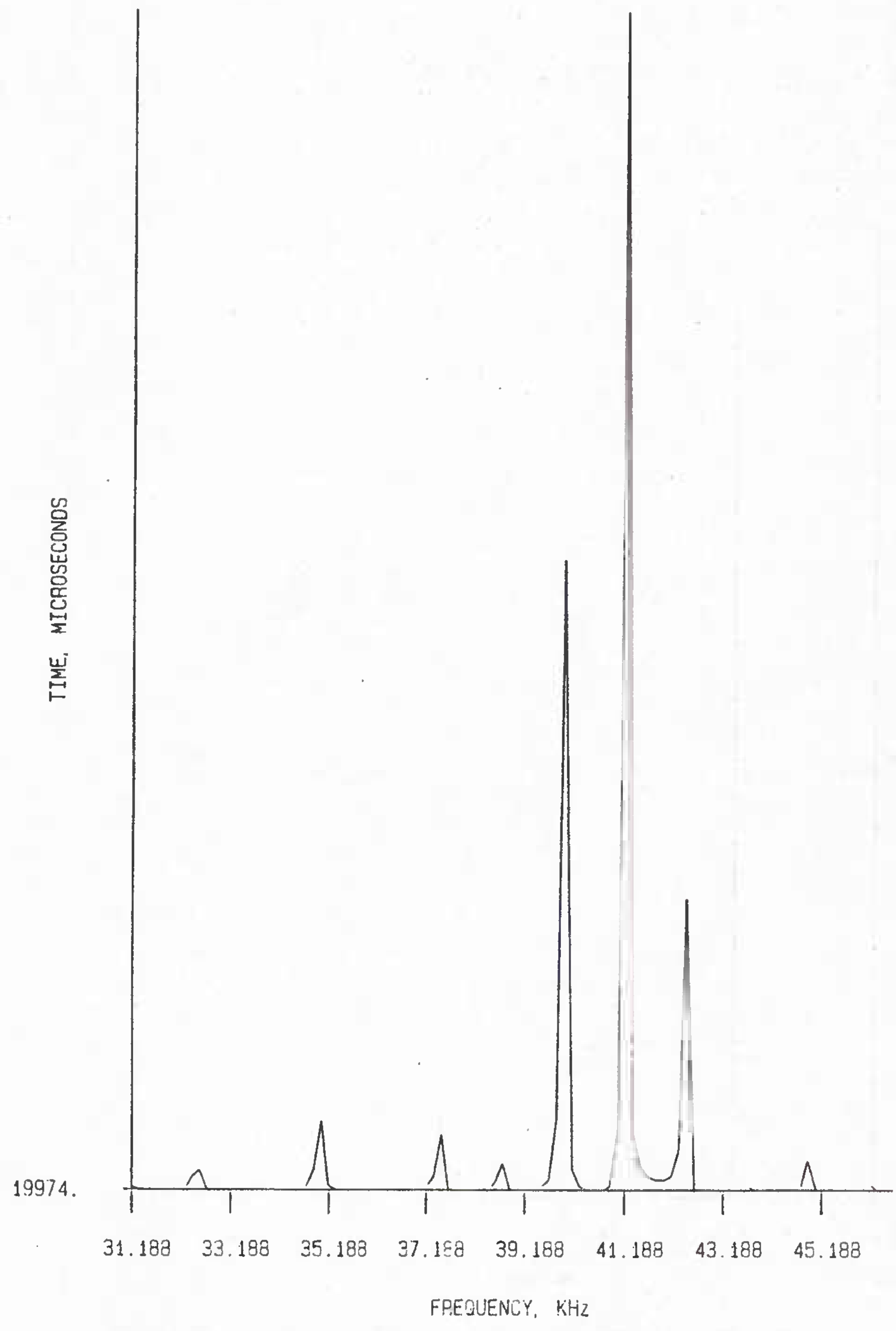


Figure 8. High Resolution FFT of Doppler Return from Firing Test

transmission, which causes an apparent shift in the wavelength. The waterfall plots can also reveal such details as the presence of in-bore balloting and yaw after muzzle exit as shown in Figure 9. The periodic secondary peaks visible at frequencies just below the primary peaks are the result of balloting motion. Although projectile attitude can not be determined directly from this information, the waterfall plot can reveal the frequency of the oscillations involved as evidenced by these secondary peaks. A projectile that did not ballot would have a waterfall plot without the secondary peaks. Figure 10 shows the case where the projectile starts moving, appears to stop when the band engages the rifling, and starts again as the pressure builds up to that required for engraving the rotating band. The resolution of the Fourier transform used for this plot is not sufficient to conclude that the projectile actually stopped, but it slowed down below the minimum resolution of the transform. This test demonstrated the value of microwave measurements in analyzing interior ballistics beyond simply a measure of muzzle velocity which is the most common use of the doppler radar in interior ballistic experiments. In fact the Muzzleschmidt is much better suited for measuring velocity at muzzle exit due to the ambiguities introduced to the microwave measurements as the doppler signal changes from a waveguide mode to free space. This transition region is clearly shown in Figures 9 and 10.

The results of aiming with a borescope were disappointing. The modified scope did not have a method for collimation, thus the accuracy of the aim point was limited to the accuracy of the machining and to the fit in the bore. If the sight was rotated in the bore or if the sight was removed and reinserted with the viewer at a slightly different angle, the apparent aim point would shift. Also the round-to-round variation of impacts on the target was not enough to allow a measurement in this short range. The precision of the gun was better than that of the borescope or our ability to measure impacts. The bore sighting and target measurements were discontinued for the second phase of the test. If a muzzle sight and witness cards are to be valuable in future tests of this sort then the muzzle sight needs to be fitted more carefully to the bore, and allowance made for some method to collimate the boresight. A borescope similar to that used for tank gunnery would be more appropriate.

The concept of the muzzle weight and the support block worked well during the test and removed transverse motion as a parameter prior to muzzle exit. This was obviously an artificial restriction and will be removed in future testing. Once the muzzle is allowed to move prior to muzzle exit then we must measure this motion, and measure it by a noncontacting method to avoid altering the response with the measurement. As an initial step the gun should be fired in the current range with the muzzle allowed to move freely. This may allow the target groups to open up enough to attempt a correlation between the muzzle position at exit and the projectile impact. For this initial test, aiming the gun from the muzzle and collecting the targets could have been done once for the entire test, as long as the same projectile and charge weight were used, because all the impacts fell on top of each other. If we are to discriminate shot fall from one round to the next with a muzzle weight in place, then the gun must be fired at a longer range, or a smaller caliber gun must be used.

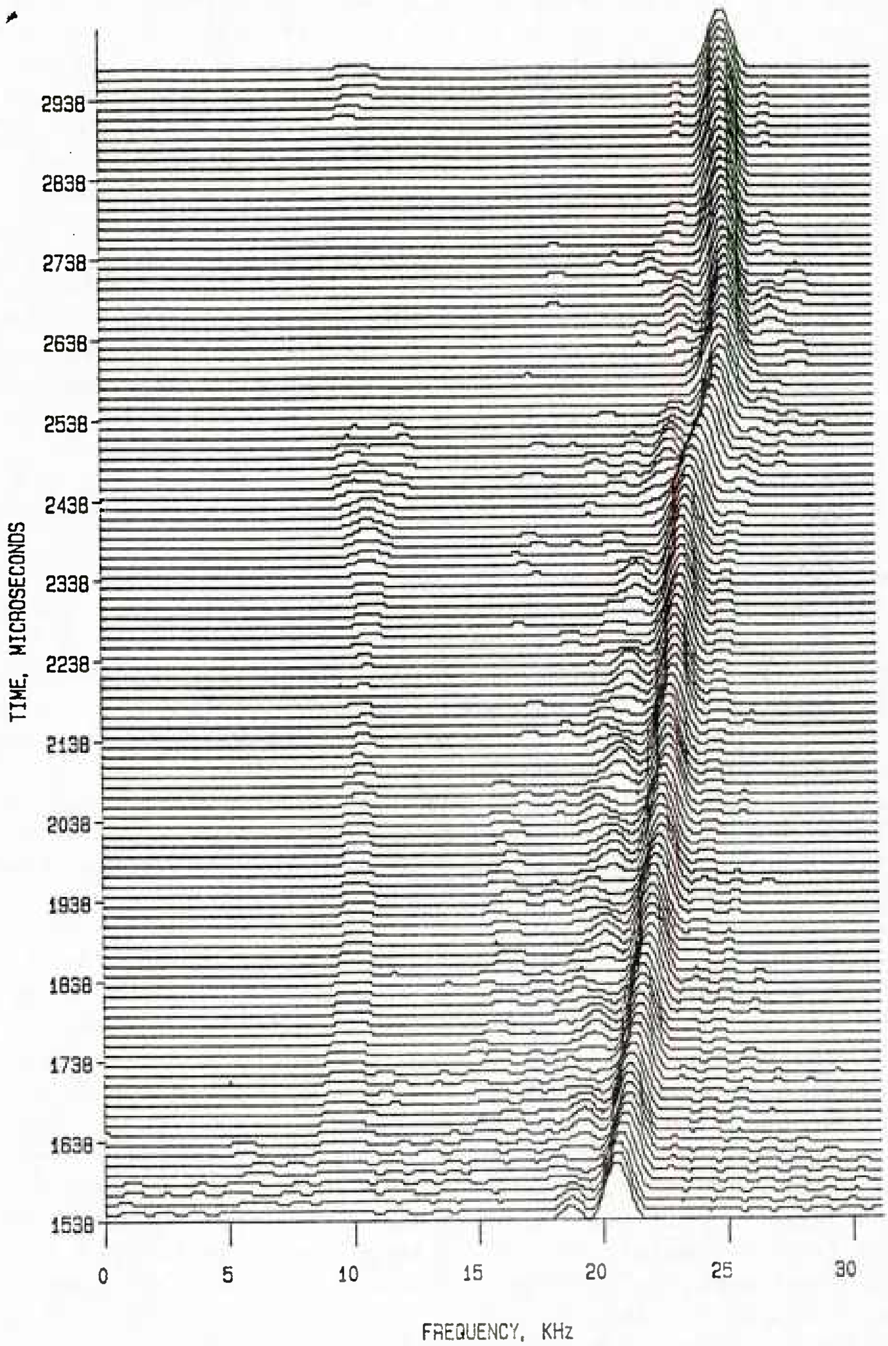


Figure 9. Waterfall Plot Showing Evidence of Balloting Motion

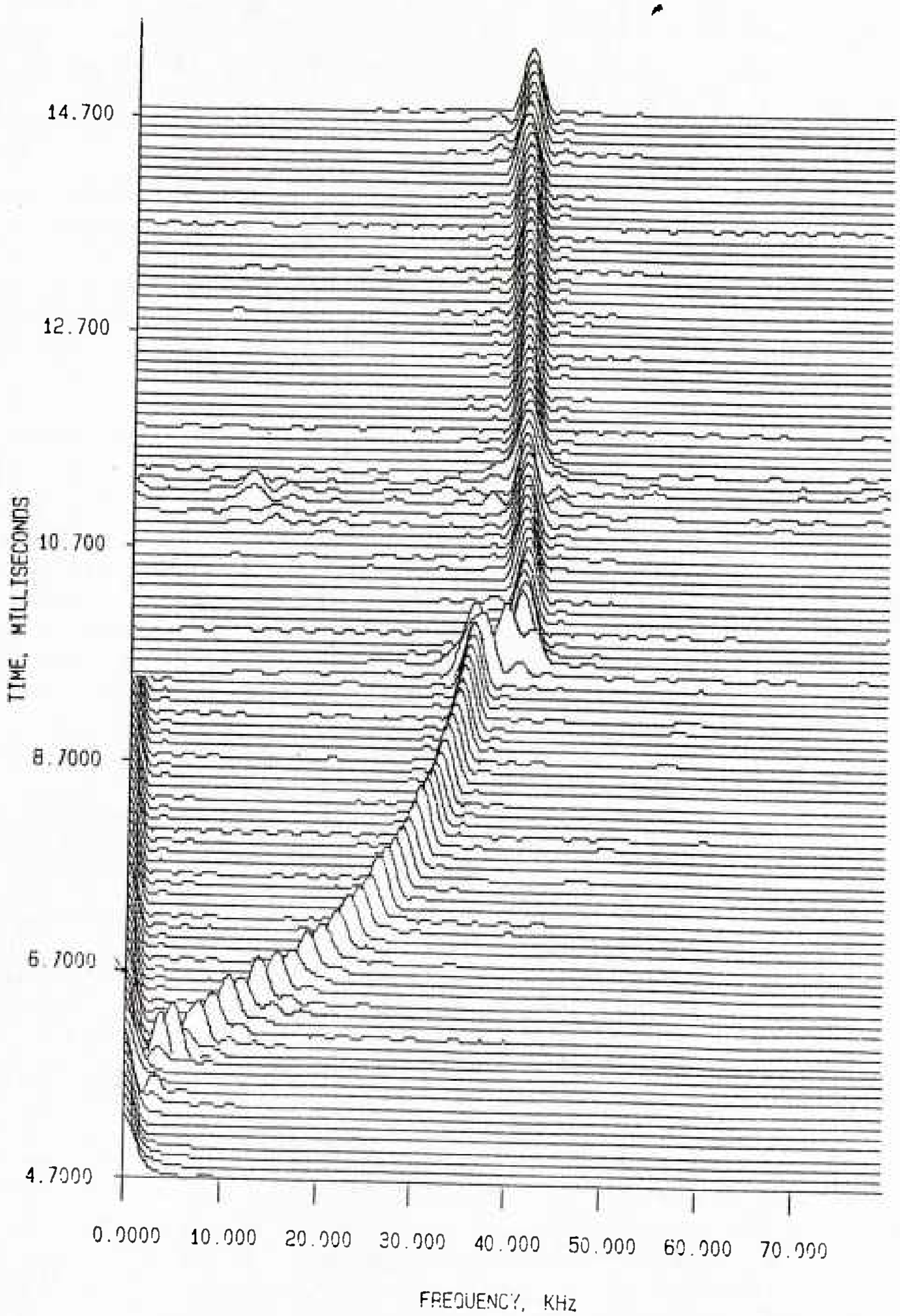


Figure 10. Waterfall Plot Showing In-Bore and Free Flight Motion

VI. APPLICATIONS

The technique to measure the spin was applied to the development of a rotating band for a 40mm model of a RAM Jet projectile. The combination of chamber pressure and microwave measurements and the flash x-ray allowed the detection of parts failures and the measurement of the percent of spinup. With this information, the time of failure and the pressure loading at failure was established. Finite element analysis resulted in the identification of the failure mechanism and the design was corrected.

The microwave and pressure measurements from firings of both the 508 and 510 projectile sizes were used by S&D Dynamics, Inc., to validate their model for projectile motion done under contract to BRL.[4] The microwave waterfall plot shown in Figure 9 was used to establish the frequency of the balloting motion experimentally. The in-bore microwave data was used to determine coefficients of friction for the model. Further development of experimental techniques would be extremely valuable in the verification of mathematical models describing the projectile and gun tube dynamics.

Future efforts that will evolve from this work include developing a 5.56-mm gun tube model of the 105-mm M68 tank gun. This rifle barrel has been physically scaled to the dimensions of the 105-mm based on the ratio of the bore diameters. Using the small gun will increase the scaled length of the range to the equivalent of a 400 m range with the tank gun and may allow us to make jump measurements in the indoor range. Additional experimentation in measurement of projectile spin in free space based on the return from the fins should be conducted to establish the signature of the projectile fins. The microwave technology will be extended by the use of a "3-D Radar", which consists of a single transmitter and three receiving antennae. This will allow a more definitive measurement of the projectile flight path and should allow the quantitative measurement of balloting and yaw.

VII. CONCLUSIONS

This report is one portion of a continuing study in projectile/gun dynamics and gun system accuracy. The objectives were not a resolution of the broad questions of accuracy and the effects of projectile/gun dynamics on system accuracy, but to make progress in the measurement and analysis of ballistic parameters that affect accuracy. The study of accuracy and jump at BRL is a multifaceted program and this work served as a baseline to help understand what is involved.

The study of projectile disengagement at the muzzle has continued based on these initial firings to a 40-mm gun tube where the muzzle was free to translate during the interior ballistic cycle. The tube motion was measured and combining the angular rate of motion of the tube with the angular rate of motion of the projectile at the muzzle represents a great stride forward in understanding the phenomenology of accuracy and jump.[8]

The microwave measurements made demonstrated the capabilities of this instrumentation technique and have led to the purchase of new instrumentation and to the development of the analysis algorithms required. The microwave data from the 37-mm gun firings were instrumental in the development of the capability to perform high resolution Fast Fourier Transforms at BRL and the application of the techniques to projectile/gun tube dynamics. The use of microwave radar to aid in the analysis of the interior ballistic performance has been extended to the 120-mm tank gun.

The continuation of the work with medium and small caliber guns in the indoor range represents an opportunity to experiment with measurement techniques and data analysis procedures at reasonable costs and in an environment that is conducive to the research effort involved. The data generated can be applied to gun tube modeling efforts both as input data and boundary conditions. The results of these efforts are readily transferred to large caliber systems such as the 105-mm and the 120-mm tank guns.

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2. F. V. Reno, "The Motion of the Axis of a Spinning Shell Inside the Bore of the Gun," BRL Report 320, Ballistic Research Laboratory, Aberdeen Proving Ground, MD; February 1943.

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5. E. M. Wineholt, R. K. Loder, "Wear Pattern of the 37-mm M3/M6/M5A1 Cannon No. 120019," BRL-MR-3376, Ballistic Research Laboratory, Aberdeen Proving Ground, MD; September 1984.

6. R. K. Loder, E. M. Wineholt, J. Q. Schmidt, "Methodology for the Determination of the Mechanism of Projectile Disengagement from the Gun," Ballistic Research Laboratory, Aberdeen Proving Ground, MD. Technical Report currently being written.

7. J.N. Walbert, "Techniques for the Analysis of Radar Doppler from Projectiles in the In-Bore and Early Free-Flight Regions," Ballistic Research Laboratory, Aberdeen Proving Ground, MD (report to appear).

8. J.Q. Schmidt, T.Q Andrews, "Joint BRL-RARDE 40-mm Firing Experiment to Assess Projectile Launch Parameter Measurement Techniques", BRL-TR-2679, Ballistic Research Laboratory, Aberdeen Proving Ground, MD; September 1985.

APPENDIX A

MULTIPLE STARGAGE MEASUREMENT AND INSPECTION DATA FORM

SHEET 1 OF 5

MULTIPLE STARGAGE MEASUREMENT & INSPECTION DATA FORM

CASTING NUMBER: X

MANUFACTURER: N.P. Co.

MODEL: M3 M6 M5A1

NUMBER: 120019

37 M/M TUBE

PROOF OFFICER: MR. BARAN W.O. 300-44111-82

NUMBER OF ROUNDS: UNKNOWN

FIRING STATUS (Check One): BEFORE / AFTER ✓

DATE OF GAUGING: 9 APR 82

37 M/M Tube M3 M6 M5A1

Main Bore - 9.55" to 78.00" 1.457" Basic Diameter

Dist. In. Rear Face Of Tube	Gage Meas. Indicated in 1/1000 of an Inch (LANDS) 1	2	3	4	5	6
77.90	+.001	+.003	+.003	+.003	+.002	+.001
77.50	1	3	3	3	2	1
77.00	1	2	3	2	1	1
76.50	1	2	2	1	1	1
76.00	1	2	2	1	1	1
75.50	1	1	2	1	1	1
75.00	1	1	2	1	1	1
74.50	1	1	2	1	1	1
74.00	1	1	1	1	1	1
73.50	1	1	1	1	1	1
73.00	1	1	1	1	1	.000
72.50	1	1	.000	1	1	0
72.00	1	1	+.001	1	1	0
71.50	1	1	1	1	1	0
71.00	1	1	1	1	1	0
70.50	1	1	1	1	1	0
70.00	1	1	1	1	1	0
69.50	1	1	1	1	1	0
69.00	1	1	1	1	1	0
68.50	1	1	1	1	1	0
68.00	1	1	1	1	1	0
67.50	1	1	1	1	1	0
67.00	1	1	1	1	1	+.001
66.50	1	1	1	1	1	1
66.00	1	1	1	1	1	1
65.50	1	1	1	1	1	1
65.00	1	1	1	1	1	1
64.50	1	1	1	1	1	1
64.00	1	1	1	1	1	1
63.50	1	1	1	1	1	1
63.00	1	1	1	1	1	1
62.50	1	1	1	1	1	1
62.00	1	1	1	1	1	1
61.50	1	1	1	1	1	1
61.00	1	1	1	1	1	1
60.50	1	1	1	1	1	1
60.00	1	1	1	1	1	1
59.50	1	1	1	1	1	1
59.00	1	1	1	1	1	1
58.50	1	1	1	1	1	1
58.00	1	1	1	.000	1	1
57.50	1	1	1	0	1	1
57.00	.000	1	1	0	1	.000
56.50	0	1	1	0	1	0
56.00	+.001	.000	1	+.001	1	0
55.50	1	0	1	1	1	0
55.00	1	0	1	1	1	+.001
54.50	1	0	1	1	1	1
54.00	1	+.001	1	1	1	1
53.00	1	1	1	1	1	.000
52.00	1	1	1	1	1	0
51.00	1	1	1	1	1	-.001
50.00	.000	1	1	1	1	1
49.00	+.001	1	1	1	1	1
48.00	.000	.000	1	1	1	.000
47.00	0	0	1	1	1	0
46.00	.000	+.001	+.001	.000	.000	+.001

SHEET 2 OF 5

MULTIPLE STARGAGE MEASUREMENT & INSPECTION DATA FORM

37 M/M TUBE	
NUMBER	120019
MODEL	M3 M6 M5A1
MANUFACTURER	N.P. Co.
CASTING NUMBER	X
PROOF OFFICER	MR. BARAN W.O. 300-44111-82
NUMBER OF ROUNDS	UNKNOWN
FIRING STATUS (Check One)	BEFORE / ✓ AFTER
DATE OF GAUGING	9 APR. 82

37 M/M Tube M3 M6 M5A1

Main Bore - 9.55" to 78.00" 1.457" Basic Diameter

Dist. In. / Gage Meas. Indicated in 1/1000 of an Inch (LANDS)

Rear Face Of Tube	1	2	3	4	5	6
45.00	+.001	+.001	+.001	.000	.000	+.001
44.00	1	1	1	0	0	1
43.00	1	1	.000	0	0	.000
42.00	1	1	0	0	0	0
41.00	1	1	0	-.001	0	0
40.00	1	1	+.001	1	+.001	+.001
39.00	1	1	1	.000	1	1
38.00	.000	.000	-.001	0	1	1
37.00	-.001	-.001	1	0	1	.000
36.00	.000	1	2	0	.000	-.002
35.00	-.001	1	.000	-.001	0	1
34.00	2	1	0	1	-.001	1
33.00	1	2	-.001	1	1	2
32.00	2	2	.000	.000	.000	2
31.00	2	2	0	0	0	2
30.00	2	1	+.001	0	0	1
29.00	1	2	.000	-.002	-.003	1
28.00	2	2	0	1	3	1
27.00	1	2	0	1	2	1
26.00	1	1	0	1	.000	2
25.00	.000	.000	0	1	0	2
24.00	0	-.001	0	2	-.001	2
23.00	0	1	0	.000	1	1
22.00	+.001	.000	0	0	1	1
21.00	1	-.001	0	0	1	.000
20.00	.000	.000	+.001	0	.000	0
19.00	+.001	0	1	0	0	+.001
18.00	1	+.001	1	0	0	1
17.00	1	1	1	+.001	+.001	2
16.00	2	2	2	1	2	2
15.00	2	2	2	2	2	2
14.75	2	2	2	2	2	2
14.50	2	2	3	2	2	2
14.25	2	2	3	2	2	2
14.00	3	2	3	3	3	3
13.75	3	2	3	3	3	3
13.50	3	3	4	4	3	3
13.25	4	3	4	4	4	3
13.00	4	3	4	4	4	4
12.75	4	4	4	4	4	4
12.50	5	4	5	5	4	4
12.25	5	4	5	5	4	4
12.00	5	5	5	5	5	5
11.75	6	5	5	5	5	5
11.50	6	5	6	6	6	6
11.25	6	6	7	6	6	6
11.00	7	7	7	7	7	7
10.75	8	8	8	8	8	8
10.50	9	9	9	9	9	9
10.25	10	10	10	11	10	10
10.00	11	11	11	11	11	11
9.75	11	11	12	12	12	12
9.65	+.012	+.012	+.013	+.013	+.013	+.012

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MULTIPLE STARGAGE MEASUREMENT & INSPECTION DATA FORM

SHEET 3 OF 5

37 M/M Tube M3 M6 M5A1

CASTING NUMBER	X
MANUFACTURER	N.P. Co.
PROOF OFFICER	MR. BARAN W.O. 300-44111-82
MODEL	M3 M6 M5A1
NUMBER OF ROUNDS	UNKNOWN
NUMBER	120019
FIRING STATUS (Check One)	BEFORE / AFTER ✓
37 M/M TUBE	
DATE OF GAUGING	9 APR. 82

<table>
<tr><th colspan="7">Main Bore - 9.55" to 78.00" 1.497" Basic Diameter</th></tr>
<tr><th>Dist. In.</th><th colspan="6">Gage Meas. Indicated in 1/1000 of an Inch (GROOVES)</th></tr>
<tr><th>Rear Face Of Tube</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>77.90</td><td>+.001</td><td>.000</td><td>.000</td><td>.000</td><td>.000</td><td>.000</td></tr>
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</table>

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MULTIPLE STARGAGE MEASUREMENT & INSPECTION DATA FORM

SHEET 4 OF 5

NUMBER	120019
MODEL	M3 M6 M5A1
MANUFACTURER	N.P. Co.
CASTING NUMBER	X
DATE OF GAUGING	9 APR. 82
FIRING STATUS (Check One)	BEFORE ☐ AFTER ✓
NUMBER OF ROUNDS	UNKNOWN
PROOF OFFICER	MR. BARAN W.O. 300-44111-82

37 M/M TUBE

37 M/M Tube M3 M6 M5A1

Main Bore - 9.55" to 78.00" 1.497" Basic Diameter

Dist. In. Gage Meas. Indicated in 1/1000 of an Inch (GROOVES)

Rear Face Of Tube	1	2	3	4	5	6
45.00	+.001	+.001	+.001	+.001	.000	+.001
44.00	1	1	1	1	+.001	1
43.00	.000	1	1	.000	.000	1
42.00	0	1	1	0	+.001	1
41.00	+.001	1	.000	0	1	.000
40.00	1	.000	0	-.001	1	+.001
39.00	1	0	-.001	2	1	1
38.00	.000	0	2	2	-.001	-.001
37.00	-.001	-.001	1	1	1	1
36.00	1	2	3	2	+.001	1
35.00	3	2	3	1	1	3
34.00	3	2	3	.000	1	3
33.00	4	3	2	+.001	1	3
32.00	3	4	3	1	-.001	1
31.00	3	3	1	.000	1	3
30.00	4	2	.000	-.001	1	3
29.00	3	1	+.001	1	2	5
28.00	1	2	.000	1	2	4
27.00	1	2	+.001	2	3	1
26.00	1	2	-.001	1	2	1
25.00	.000	1	.000	3	1	2
24.00	0	1	-.001	1	2	3
23.00	0	1	1	3	2	1
22.00	0	1	1	3	2	2
21.00	0	1	2	4	3	1
20.00	0	.000	1	2	4	1
19.00	0	0	2	3	1	1
18.00	0	0	2	2	1	1
17.00	0	0	.000	2	.000	.000
16.00	0	0	0	+.001	0	0
15.00	+.001	+.001	0	1	+.001	0
14.75	1	1	0	1	1	+.001
14.50	1	1	+.001	1	1	1
14.25	1	1	1	1	1	1
14.00	1	1	1	1	1	1
13.75	1	1	1	1	1	1
13.50	1	1	1	1	1	1
13.25	1	1	1	1	1	1
13.00	1	1	1	1	2	1
12.75	1	2	1	2	2	1
12.50	2	2	2	2	2	1
12.25	2	2	2	2	2	1
12.00	2	2	2	2	2	2
11.75	3	3	2	3	2	2
11.50	3	3	3	3	3	3
11.25	4	4	3	3	3	3
11.00	4	4	4	4	3	3
10.75	4	4	4	4	4	4
10.50	4	5	5	5	5	4
10.25	5	6	5	5	5	5
10.00	6	6	6	6	5	5
9.75	5	7	6	6	6	5
9.65	+.005	+.007	+.007	+.006	+.006	+.006

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SHEET 5 OF 5

37 mm TUBE, M3, [redacted], M5A1, M6, [redacted]	CHAMBER 0" TO 9.20" (BASIC)

DISTANCE (INCHES) FROM					GAUGE MEASUREMENTS INDICATED IN 1/1000 OF AN INCH					
					[redacted] OR Y			[redacted] OR X		
REAR FACE OF BREECH	MUZZLE FACE	REAR FACE OF TUBE	BASIC DIAMETER	ZERO	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE	GAUGE READING	ACTUAL DIAMETER	DIFFERENCE
GUN	TUBE	TUBE								
13.60	68.90	9.10	1.510	1.510	+.008	1.518	+.008	+.008	1.518	+.008
12.50	70	8	1.510		8	.518	8	8	.518	8
11.75	70.75	7.25	1.510		+.007	1.517	+.007	+.006	1.516	+.006
10.25	72.25	5.75	1.9408	1.900	+.042	1.942	+.001	+.043	1.943	+.002
9.50	73	5	1.9459		49	949	3	49	949	3
8.50	74	4	1.9527		57	957	4	57	957	4
7.50	75	3	1.9595		64	964	4	64	964	4
6.50	76	2	1.9663		71	971	5	71	971	5
5.50	77	1	1.9731		77	977	4	77	977	4
5.00	77.50	.50	1.9765		80	980	3	81	981	4
4.60	77.90	.10	1.9799		+.083	1.983	+.004	+.083	1.983	+.004

SPECIAL MEASUREMENTS

	BASIC	ACTUAL		BASIC	ACTUAL
TOTAL LENGTH OF GUN	82.50"	—	ROTATION OF TUBE AT BREECH	.00°	—
TOTAL LENGTH OF TUBE	78.00"	78.00"	MOVEMENT OF TUBE AT BREECH	.000"	—
DEPTH OF BREECH RECESS	4.50"	—	NUMBER OF LANDS AND GROOVES	12	12
ADVANCE OF RIFLING (PLUG GAUGE)	.00"	—			

Borescoped: (Not Chrome Plated)

Light scratches, stains, carbon and other deposits throughout chamber and main bore. Piezo gage hole drilled through chamber wall (plugged) 4.25" from rear face of tube (RFT) in the 12:00 o'clock area. Light heat checking encircling centering cylinder beginning 7.50" from (RFT) and extending forward into main bore to 20" from (RFT). Light erosion encircling centering cylinder beginning 8" from (RFT) and extending forward into main bore to 14" from (RFT). Edges of lands are rounded throughout eroded area. Light longitudinal scoring encircling centering cylinder beginning 8" from (RFT) and extending forward into main bore to 12" from (RFT). Light to moderate coppering throughout main bore, more pronounced between 17" and 40" from (RFT). One hole drilled through tube wall in groove at 4:30 o'clock 77.75" from (RFT).

No photos or impressions taken at this time.

Twist of Rifling: Uniform 1 turn in 25 calibers.

STAMPED NONE	STARGAUGED AND INSPECTED BY D. TESCH	REVIEWED BY
RODMAN D. KING	TIME	COMPILATOR
RECORDER J. McWILLIAMS	PLACE 525	GRAPHED BY

37 M/M TUBE #120019 M3, M6 OR M5A1
9 APR. 82 A.F. UNKNOWN Rds.
FOR: BARAN
300-4411-82

APPENDIX B

DIMENSIONS OF INDIVIDUAL ROUNDS FIRED

APPENDIX B

DIMENSIONS OF INDIVIDUAL ROUNDS FIRED

Projectile	L1(mm)	L2(mm)	L3(mm)	L4(mm)	L5(mm)	L6(mm)	L7(mm)	L8(mm)	D1(mm)	D2(mm)	D3(mm)	D4(mm)	D5(mm)	D6(mm)	D7(mm)	D8(mm)	Proj. Weight (g)	C.G. Location From Front(mm)
508 A	14.81	4.50	7.21	9.32	18.67	66.75	100.63	105.74	36.50	36.53	38.25	36.91	38.25	37.16	36.53	36.88	868	54.02
508 B	14.83	4.55	7.21	9.35	18.69	66.68	100.66	105.74	36.53	36.53	38.25	36.91	38.25	37.18	36.55	36.88	867	54.05
508 C	14.81	4.65	7.19	9.35	18.67	66.83	100.63	105.64	36.55	36.53	38.25	36.91	38.25	37.18	36.55	36.86	867	53.92
508 D	14.81	4.01	7.24	9.37	18.69	66.87	100.74	105.79	36.47	36.47	38.28	37.01	38.28	37.29	36.47	36.86	868	53.98
508 E	14.78	4.24	7.16	9.32	18.69	66.83	100.66	105.82	36.58	36.58	38.23	36.88	38.22	37.13	36.58	36.88	869	53.90
508 H	14.91	4.37	7.18	9.45	18.77	66.93	100.56	105.61	36.53	36.53	38.23	36.91	38.23	37.18	36.53	36.88	867	53.92
508 I	14.25	4.24	7.21	9.32	18.67	66.24	100.13	105.69	36.58	36.58	38.25	36.91	38.25	37.11	36.58	36.86	866	53.80
508 J	14.83	4.52	7.21	9.32	18.64	66.72	100.56	105.84	36.50	36.50	38.25	36.91	38.25	37.18	36.52	36.86	867	53.82
508 K	14.78	4.34	7.19	9.30	18.67	66.70	100.53	105.34	36.47	36.47	38.25	36.91	38.25	37.16	36.47	36.86	866	53.70
508 M	14.73	4.42	7.19	9.35	18.64	66.78	100.58	105.79	36.50	36.53	38.28	36.91	38.25	37.29	36.52	36.86	867	53.90
508 X	14.48	4.47	7.16	9.30	18.59	67.21	100.51	105.64	36.47	36.45	38.23	36.88	38.25	37.21	36.45	38.88	864	53.77
508 Y	14.40	4.44	7.06	9.22	18.54	68.55	101.90	107.04	36.58	36.58	38.25	36.91	38.25	37.13	36.58	36.88	879	54.41
mean	14.70	4.40	7.18	9.33	18.66	66.92	100.67	105.81	36.56	36.52	38.25	36.91	38.25	37.18	36.53	36.87	867.9	53.93
σ	0.198	0.164	0.043	0.051	0.054	0.534	0.397	0.393	0.041	0.042	0.016	0.031	0.013	0.054	0.043	0.010	3.546	0.174

Note: All other rounds fired were not dimensioned.

APPENDIX C

SUMMARY OF ACQUIRED DATA

APPENDIX C

SUMMARY OF ACQUIRED DATA

ID Number	Projectile Number	Projectile Type	Charge Weight	Doppler Radar Low Pass FM Channl	Doppler Radar Band Pass FM Channel	Doppler Radar Direct Record Channel	Muzzleschmidt # of Channels Recorded	Chamber Pressure KPSI*	Orientation of Grooves	Radar Freq. GHz	
25	-----	508	110	Okay	N/G	N/G	8	Okay	None		
26	-----	508	110	Okay	N/G	Okay	6	Okay	none		
27	-----	508	110	Okay	Okay	Okay	4	Okay	none		
28	-----	508	110	Okay	Okay	Okay	7	Okay	none		
29	-----	508	110	Okay	Okay	Okay	6	Okay	none		only in-bore radar
30	-----	508	110	Okay	Okay	Okay	7	Okay	none		
31	A	508	110	Okay	Okay	Okay	7	36	vert.	10.040	
32	B	508	110	Okay	Okay	Okay	7	Okay	horiz.	10.049	
32	C	508	110	Okay	Okay	Okay	7	Okay	vert.	10.045	
34	D	508	110	Okay	Okay	Okay	7	Okay	horiz.	10.043	
35	E	508	110	Okay	Okay	Okay	6	39.6	vert.	10.040	
36	H	508	110	Okay	Okay	Okay	6	Okay	horiz.		
37	I	508	110	Okay	Okay	Okay	6	Okay	vert.		
38	J	508	110	Okay	Okay	Okay	6	Okay	horiz.	10.060	excellent radar return
39	K	508	110	Okay	Okay	Okay	6	Okay	vert.	10.063	
40	M	508	110	Okay	Okay	Okay	6	Okay	horiz.	10.061	
41	X	508	110	Okay	N/G	Okay	6	Okay	vert.	10.059	
42	Y	508	110	Okay	Okay	Okay	6	Okay	horiz.	10.045	
43	-----	508	140	N/G	N/G	N/G	-----	N/G	none		
44	-----	508	140	Okay	Okay	Okay	6	Okay	none		
45	-----	508	140	Okay	Okay	Okay	6	Okay	none		
46	-----	508	150	Okay	Okay	Okay	6	Okay	none		
47	-----	508	160	Okay	Okay	Okay	6	Okay	none		
48	-----	508	160	Okay	Okay	Okay	6	67	none		
49	-----	508	160	Okay	Okay	Okay	6	69.2	none		
50	-----	508	155	Okay	Okay	Okay	6	63	none		
51	-----	508	155	Okay	Okay	Okay	6	64.3	none		
52	-----	510	160	Okay	Okay	Okay	6	Okay	none	10.058	only in-bore radar
53	-----	510	160	N/G	N/G	N/G	6	48.8	none		
54	-----	510	160	Okay	Okay	Okay	6	49.	none		
55	-----	510	130	Okay	Okay	Okay	6	36.8	none		
56	-----	510	110	Okay	Okay	Okay	6	N/G	none		
57	-----	510	110	Okay	Okay	Okay	6	30	none		good shot.

* Pressure records were only analyzed for rounds where necessary for test.
N/G (not good) implies measurement problem.

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